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# Studies of Braille Reading Rates and Implications for the Unified English Braille Code

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***Abstract:*** Reading rate data was collected from both print and braille readers in the areas of mathematics and literary braille. Literary braille data was collected for contracted and uncontracted braille text with dropped whole-word contractions and part-word contractions as they would appear in the Unified English Braille Code. No significant differences were found between contracted and uncontracted braille reading rates or between print and Nemeth oral reading rates. Reading rates in cells per second for mathematics were slower than for literary material in both print and braille.

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This article is the third in a series of three articles that address the concerns of the Braille Authority of North America (BANA) regarding the Unified English Braille Code (UEBC)--also known as Unified English Braille (UEB). The first article (Wetzel & Knowlton, 2006) focused on groups of transcribers, teachers, and users of braille who expressed their professional opinions and concerns about UEBC and proposed areas for future research. The second article (Knowlton & Wetzel, 2006) addressed differences in the length of text between UEBC and the English Braille American Edition (EBAE), the Nemeth code, and the braille computer code as used in the United States. This article addresses reading rates for different types of literary and mathematical text and relates the findings to the proposed UEBC.

With the development of UEBC over the past decade, BANA has been faced with the challenging decision of whether to adopt the new unified code, adopt portions of the new code, or maintain the status quo of EBAE. The research presented here examined the impact of making changes in the current braille code. The results provide insights into, not definitive answers to, questions about braille codes, and provide direction for additional research that is needed to answer significant questions before wholesale changes to the code are adopted.

Earlier research (Knowlton & Wetzel, 1996) demonstrated that braille reading rates are not constant, but vary widely, depending on the purpose of the reading task. Further research (Wetzel & Knowlton, 2000) demonstrated that braille and print reading rates varied in a parallel manner, with the braille rates always slower than the print rates, but affected to a similar degree by the task. Using this information as a starting point, we decided to address three kinds of reading tasks in this study: oral text reading, text scanning, and oral mathematics reading.

## Studies of braille reading of literary text

The experimental research to address the literary braille reading rates created by changes to EBAE by UEBC encompasses five different issues:

1. Replication of studies of reading rates in contracted and uncontracted braille (Legge, Madison, & Mansfield, 1999)
2. The effect of eliminating spacing between the words *and*, *for*, *of*, *the*, *with* and *a*
3. The effect of dropping the whole-word contractions for *to*, *into*, and *by*
4. The effect of dropping single part-word contractions for *com*, *ally*, *dd*, *ation*, and *ble*
5. The effect of dropping multiple part-word contractions.

To examine the issues of reading UEBC, we decided to use a paradigm developed by Legge et al. (1999) for the braille edition of MNRead while embedding changes to the braille code that would be in place if UEBC were adopted. MNRead is a test to assess oral reading rates and is standardized in print, uncontracted braille (Grade 1), and contracted braille (Grade 2). The print test is composed of a set of sentences of 60 cells in length, each of which is placed on a card in three lines of 20 cells each. An example of one of the MNRead stimuli cards is presented in Figure 1.

The text presented is at a fourth-grade reading level. The braille versions of MNRead are transcriptions of the print form, presented in a similar format with or without contractions or spacing, depending on whether contracted or uncontracted braille is being considered. The line length in braille can vary from the 20 cells per line, but a 3-line presentation for each sentence is preserved.

The braille data can be analyzed in words per minute or cells per second (CPS). If a cells-per-second analysis is used for braille, the complications created by nonspaced words and the use and nonuse of contractions can be circumvented but still provide a reliable way to compare reading in the two forms of braille. When they computed reading rates in cells per second, Legge et al. (1999) found no significant differences between contracted and uncontracted oral braille reading rates for the same individual. A cells-per-second model was used, since the subjects would be reading mathematical numbers, equations, and spatial problems. A "word" model for determining text length does not fit strings of multiple-digit numbers or mathematical equations. A "cell" model for braille and a "character" model for print is used in these studies.

## METHODS

### *Design*

This study was developed as a 3 x 2 x 4 mixed factoral design. Fifty-two participants were assigned to one of three groups: print, contracted braille, and uncontracted braille. Two orders of stimulus presentation were used for each group, and each group received each of the four different experimental treatments.

### *Participants*

The participants were recruited from a large midwestern city and were paid $25 each for their participation. They had used either print or braille as their primary reading mode for at least 12 years and considered themselves to be proficient in reading. The braille readers were chosen for their expertise in reading text in EBAE. They were randomly assigned to one of two different random orders of braille stimuli. All the participants read the same literary text.

### *Stimuli*

In addition to the baseline data collected via the MNRead cards, the participants in each group were presented with four experimental conditions: (1) changes in the reading rate caused by inserting spaces after the words *and*, *for*, *of*, *the*, and *a* when they follow each other in the text; (2) the impact of dropping the whole-word contractions *to*, *into*, and *by* and inserting a space after them, as in print; (3) the elimination of the part-word contractions *com*, *ally*, *dd*, *ation*, and *ble*; and (4) the elimination of multiple part-word contractions.

In these experimental conditions, each word or contraction was examined separately. For each condition, a set of six sentences was developed. Each sentence was placed on a separate card. Each sentence contained the word or contraction at least twice. The participants were asked to read the sentences orally as quickly as possible. They were timed on each card, and errors in reading were noted.

### *Procedure*

The participants were called and scheduled to participate in the study at their convenience. The participation time ranged from 40 to 60 minutes. The participants first completed the brief questionnaire to provide basic demographic information for the study. Next, they were assigned to one of the three groups on the basis of their interest and qualifications and then assigned to one of the two different presentation orders within their assigned group. The participants were then presented with one stimulus card at a time. They were instructed to read the card aloud as quickly as possible and told when to start. The reading time for each stimulus was recorded in seconds. The session was also taped for future review, if it was found necessary.

All the stimuli were short and at about the fourth-grade reading level. Since the participants were all adult volunteers, extensive practice was not thought to be necessary. The participants were given six trials in each condition. The first trial was considered a practice trial. Only the data for the remaining five stimuli were scored. The data for each participant were entered into an Excel spreadsheet to allow for comparison between groups or within groups as needed and were coded by reading task, order, and demographic information. The individual reading time for each stimulus card was then entered into the database.

The participants were first asked to read six passages from the MNRead stimuli developed by Legge et al. (1999) in print, uncontracted braille, or in contracted braille. The reading of these stimuli produced the cell-per-second data that provides the baseline to which the other research data are compared.

### *Scoring*

For each stimulus, we decided to use the number of cells per second as opposed to the number of words per minute to create consistency within the analysis. The total number of cells for each item was divided by the reading time for that item. This provided the number of cells per second read by each participant.

## RESULTS

The comparison of uncontracted braille and contracted braille confirms the results of earlier research by Legge et al. (1999). The oral reading rate for contracted braille was 7.90 CPS, and the oral reading rate for uncontracted braille was 7.95 CPS ($t = 2$, $p < .995$).

Condition 1 addressed the effect on braille reading rates when spaces are inserted after the words *and, for, of, the, with,* and *a* when they follow each other in text. This is a change from EBAE that is currently proposed by UEBC. The impact of adding spaces between these words was not statistically significant. Seventeen participants generated an average reading rate of 7.101 CPS without spaces. When spaces were added, the reading rate dropped to 6.89 CPS ($t = 2.832$, $p = .115$).

Condition 2 addressed the effect on literary text of dropping the three whole-word contractions *to, into,* and *by*, as proposed by UEBC. For the contractions *into*, the contraction for *in* is preserved, but *to* is spelled out. These results are not consistent. The use and nonuse of *to* and *by* is clearly nonsignificant, but for *into*, the probability that the contracted reading rate will be faster is significant at a level of .05. The results are presented in Table 1.

Condition 3 compared the oral braille reading rates with and without five specific part-word contractions. The results are presented in Table 2. The contractions addressed are *com, ally, dd, ation,* and *ble*. For the contraction *ation*, the letter *a* is followed by the contraction *tion*. These contractions would not be used in UEBC.

The results of the literary comparisons of stimuli are clear. For all the contractions, the reading rates were significantly slower than the MNRead cell-per-second scores using contracted braille. Furthermore, the reading rates, computed in cells per second, for the fully contracted braille were always significantly faster than were the reading rates for braille with selected contractions dropped. Each reading-rate analysis was highly significant ($p < .02$).

Condition 4 was a brief study that addressed the reading rates as a function of dropping multiple contractions within a passage. In this condition, reading rates again dropped precipitously, from 7.092 to 4.37 CPS. However, there was a significant order effect in this segment of the study, with the slower readers showing a much larger drop in reading rates than the faster readers. There is no explanation for this finding.

### SUMMARY OF THE FINDINGS FOR LITERARY BRAILLE READING

The conclusion we are able to draw from these results is equivocal. There is a definite trend toward longer reading time in cells per second for passages with dropped contractions, but the pattern is not clear. This lack of clarity may be due to the small number of sentences presented in each condition (5) or the relative shortness of the passages (the average number of cells was 47). In addition, these sentences were tightly controlled; only one contraction was eliminated for each passage. There is a significant question remaining as to the impact of eliminating multiple contractions in a passage. It is a question that should be addressed before global changes to the braille code are made. These issues can be most effectively addressed by conducting further research.

Reading of literary material, as measured in cells per second, indicated no significant differences between contracted and uncontracted braille reading rates. Nor was there a significant difference in reading rates (again in cells per second) between spaced and unspaced text versions for the words *and, for, of, the, with,* and *a* as they would appear in UEBC. Dropping contractions for the whole words *to, into,* and *by* presented mixed results. A significant difference in reading rates occurred with the contraction for *into.* The cells per second were higher in the contracted text than in the uncontracted text. However, it must be kept in mind that higher reading rates in cells per second do not necessarily mean faster reading times if the text is uncontracted. The total reading time ultimately depends on the total number of cells to be read. This point is significant when examined in the perspective of other research (Knowlton & Wetzel, 2006) regarding total cell counts in EBAE or Nemeth code and UEBC text samples, where it was found that primary grade-level literary text in UEBC was 4% to 7% longer.

Comparisons of the oral reading of text with *com, ally, dd, ation,* and *ble* in both contracted and uncontracted forms were all highly significant ($p < .02$). There is a definite trend toward longer reading times in cells per second when these contractions are not used. No data are currently available to determine if this is an issue that may be explained as part of a learning curve. The participants, all expert braille readers, expected to read contracted braille and may initially have been slowed down when they were confronted by unfamiliar written forms.

## Studies of braille reading of mathematical text

In beginning to address studies in braille mathematics reading, we were unable to locate any recent research related to reading rates for mathematics in either print or braille. Without an established standard, we decided to collect data for print reading rates and braille rates in the reading of mathematics. The experimental tasks included (1) reading single-digit numbers; (2) reading double-digit numbers; (3) reading triple-digit numbers; (4) reading mixed one-, two-, and three-digit numbers; (5) reading one-, two-, and three-digit numbers mixed with one-, two-, and three-digit words; (6) reading numbers embedded in word problems; (7) reading a computational format; and (8) scanning text for upper-cell and lower-cell positioned numbers.

## METHODS

### *Design*

This study was developed as a 2 x 2 x 8 mixed factorial design. Forty participants were assigned to one of two treatment groups (print or braille) and one of two stimuli presentation orders. The orders were different random sequences of the same 48 individual stimuli cards.

### *Participants*

As in the reading study, the participants were recruited from a large midwestern city and were paid $25 each for their participation. They were scheduled to participate at their convenience, and the participation time ranged from 40 to 60 minutes.

### *Stimuli*

Print stimuli were developed in the format of 60 cells in three lines per card. In mathematical material, it was not always possible to observe this format fully, but each stimulus card adhered to the format as closely as possible. Sets of stimuli cards were developed for reading random one-, two-, and three-digit numbers, as well as cards with mixed digits; random mixed digits interspersed with random one-, two-, and three-letter words; and texts with embedded numbers. A set of six cards was produced for each condition.

The print stimuli were transcribed into EBAE or Nemeth code. Duplicate sets of the braille stimuli were created that differed only in whether the numbers were in literary positions (upper cell) or the Nemeth code positions (lower cell). Three final sets of mathematical stimuli were developed. The first set consisted of short word problems that included numbers; these problems were transcribed into braille with numbers in the literary position (upper cell) and braille with numbers in the Nemeth code notation (lower cell). The second set of stimuli consisted of problems for elementary computation of addition, subtraction, division, and fractions; these problems were provided only in the Nemeth code. The third set of stimuli were longer passages that contained recipes with measurements indicated by numbers. Again, duplicate sets presented numbers in the literary and Nemeth code notations. These passages were created to obtain data on scanning rates for numerical information in EBAE and the Nemeth numbers. For clarity, an example of one of the stimuli cards for the mixed 1-3-cell numbers with 1-3-cell words is presented in Figure 2.

### *Procedures*

The participants first completed the brief questionnaire to provide basic demographic information for the study. They were then assigned to one of the three participant groups, on the basis of their interest and qualifications, and to one of the two presentation orders. The participants were instructed that they would be presented with one stimulus card at a time, that they would be told when to start reading, and that they should then read each card aloud as quickly as possible. The reading time for each stimulus was recorded in seconds. The session was also taped for future review, if it was found necessary.

The participants were given six trials in each condition. The first trial was considered a practice trial. Only the data for the remaining five stimuli were scored. The data for each participant were entered into an Excel spreadsheet to allow for comparison between groups or within groups as needed and were coded by reading task, order, and demographic information. Individual reading time for the stimulus cards was then entered into the database.

The participants read six cards from the MNRead stimuli developed by Legge et al. (1999) to collect baseline reading data. They read in print, uncontracted braille, or contracted braille, depending on which group they had been assigned to. The reading of these stimuli produced the cell- or character-per-second data that provided the baseline to which other research data were compared.

## RESULTS

An initial analysis compared oral print and braille reading rates of mathematical material. A one-way analysis of variance (ANOVA) was conducted for one-digit, two-digit, and three-digit numbers, as well as for the mixed conditions of one-, two-, and three-digit numbers (which were two-, three-, and four-cell numbers in braille) and one-, two-, and three-digit numbers randomly mixed with one-, two-, and three-cell words. Mathematical expressions and spatially formatted computational problems of addition, subtraction, multiplication, and division were also examined. The results are presented in Table 3. Of noteworthy interest is the finding that there was no significant difference in reading rates in any of these conditions when reading print and braille using a cell-per-second model were compared.

Both print and braille oral reading rates for mathematics were lower than those for literary reading, but no significant difference between the oral reading rates for print and braille mathematics was found.

Separate comparisons of literary numbers versus Nemeth code numbers presented mixed results. There were significant differences in the reading rates for single digits ($p < .0001$) and mixed one- to three-digit numbers ($p < .01$). In both cases, the literary numbers were read faster. However, in four other experimental conditions--double digits, triple digits, mixed numbers and words, and reading text with embedded numbers--there was no significant difference in reading rates (see Table 4).

A final experimental condition to address the ability to scan text for numbers required the participants to read instructions for cooking recipes silently and then to search the text for responses to specific questions that were related to the quantities stated in the text. The text conditions presented numbers in either EBAE or the Nemeth code positions. There was no significant difference in the scanning rates for the two conditions ($p < .966$).

### SUMMARY OF THE FINDINGS ON MATHEMATICAL READING RATES

The comparison of the oral reading and scanning rates of EBAE and the Nemeth codes yielded mixed results. The oral reading rates were significantly faster for literary numbers (EBAE) than for the Nemeth code numbers in the conditions of reading single digits and randomly mixed single, double, and triple digits. There were no significant differences between the oral reading rates for reading double-digit, triple-digit, mixed one-digit number with one- to three-cell words, and embedded numbers in the text. A final study on scanning rates for numbers embedded in print revealed no significant difference between the literary and Nemeth numbers. When one looks at the impact of these findings, in combination with the results from other text analyses (Knowlton & Wetzel, 2006), which demonstrated a significantly increased text length as a result of the proposed code changes, there is a reason for concern, particularly during a transition phase in which a large learning curve may be in effect. Knowlton and Wetzel (2006) found that the mathematical computational format, algebra, and calculus were 21% to 54% longer in UEBC, linear arithmetic was only 1% longer, and computer code samples were 1% longer to 4.5% shorter. The small number of stimuli presented in this investigation does not allow for any prediction about the length of that learning curve or the time frame in which expert readers will again be reading at their previous higher reading rates, as measured in cells per second. Overall, however, a longer text length would require a longer total reading time.

### LIMITATIONS

The results obtained in these studies of reading mathematical braille need to be interpreted with the same degree of caution as the results of the literary studies. The participants were asked to read a series of numbers and mathematical expressions orally. The average number of braille symbols per card was 60 cells. The actual number of cells read per card varied. These were short segments of text.

This research provides the first studies in the reading rates of braille mathematics based on the reading rates of 40 adult expert braille readers. Although these numbers were sufficient for statistical analysis, the findings may not be applicable to larger populations and to novice braille learners. Also, the findings presented here are based on expert braille readers reading only five samples of each condition of text. It is not possible to plot a learning curve for the kinds of changes made in these studies. It would be informative to know how the changes to the code will affect reading rates and the time it would take to become competent in using them.

This was a specific task, assessing oral reading speed as a reliable indicator of reading rate, but it is not a real-world situation. The comparable reading conditions need to be addressed with more actual stimuli. An interesting finding is that there were no significant differences in reading speed between upper and lower cell numbers when two-digit, three-digit, and number and word were read and the recipe material was scanned. More complex tasks may be somewhat more indicative of the real world. The reading rate may be influenced more by the number of cells, spacing, and nature of the reading task than by the position of numerical symbols in the braille cell. Additional tasks, including writing and the manipulation of written mathematical material, as in calculation and problem solving, may provide additional information on how braille codes are actually used.

## Conclusion

When one looks at the results collectively, it is clear that much more research is necessary before professionals will have sufficient knowledge to make wise decisions regarding changes to the braille codes. Such studies should cover a wide range of topics related to the ways in which written knowledge is encoded, accessed, and used. Researchers and other professionals who work in the field of visual impairment need to examine different kinds of written information and how braille readers use the information in their activities.

Writing braille is an area of research that is yet to be addressed. The use and nonuse of contractions and spacing may affect the efficiency of writing, and the increased number of cells may inhibit the efficiency of text manipulation and mathematical calculation. There may also be limits related to memory load and the attention required for this kind of text manipulation.

To date, no studies have addressed the reading of graphic material in braille. The fields of geometry, trigonometry, and calculus rely heavily on graphics. Maps, charts, graphs, and diagrams also encode information in a manner that requires the use of lines, points, and areas, and text for labeling significant parts. A unified code needs to address this kind of information in addition to pure literary text.

Perhaps some of the most significant research on any braille code needs to address a vast array of cognitive issues that are related to learning and using braille as a reading and writing system. Researchers need to replicate the current studies in both the literary and mathematics fields using longer stimuli selections and diverse levels of text with a range of complexity and including individuals with diverse intellectual abilities as participants.

The field would benefit from studies that address limits to short-term memory (working memory) as they apply to the reading, recall, and writing of braille. Limits of short-term memory are acknowledged to be at a level of $7 \pm 2$ items (or bits) of information (Kalet, 2005). Certain common mathematical notations easily exceed this limit in UEBC, which may affect the ability not only to learn and remember information accurately, but to manipulate it in problem solving. Finally, professionals need to address the learning curve as individuals of all ages learn to read and write braille. Such studies would greatly inform us as we make decisions that affect students of braille and give them access to diverse sorts of information.

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